OBSERVATION AND MODELING OF ANTARCTIC ICE SHEET AND OCEAN CIRCULATION INTERACTIONS

Director's Research and Development Fund (DRDF)
Interim Report

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A. OBJECTIVES

Our objective was to couple the Ice Sheet System Model (ISSM), a new three-dimensional, high-resolution, higher-order model of the Antarctic ice sheet, with the global ocean, sea-ice, and ice shelf cavity model developed by the Estimating the Circulation and Climate of the Ocean, Phase II (ECCO2) project. The coupled model would then be integrated to provide a more realistic description of ice flow in Antarctica, ice shelf cavity melting, and ocean circulation around Antarctica, and to enable the development of sensitivity studies to determine the evolution of the Antarctic ice sheet into a warming climate.

B. APPROACH AND RESULTS

1. Coupling of ISSM and ECCO2

a. Anisotropic meshing routines to adapt to high-resolution ECCO2

ISSM [1] is a finite-element–based ice flow model, running on highly anisotropic meshes (see Figure 1, upper left frame), while ECCO2 is based on finite differences, running on regular grids (see Figure 2, upper right and lower left frames). In order to transfer data between ISSM and ECCO2 in a coupled run, two options are available. First, one can interpolate the data from the mesh onto the grid, and vice-versa. This solution is easy to implement on a technical level, but it introduces interpolation errors that can be detrimental to the coupling. Second, one can build the grids and meshes in such a way as to share common vertices. This approach, which was adopted in this project, is more difficult to implement on a technical level, but it has the advantage of introducing no interpolation error.

Figures 1 and 2 show meshes and grids for the Pine Island Glacier in Antarctica, in which the anisotropic mesh (on the grounded part of the ice sheet, Figure 1 upper left frame) was adapted to correspond exactly to a 1-km resolution grid on the ocean (Figure 2, upper left and lower right frames). The mesh was used to run ISSM in assimilation mode, in order to infer basal drag (Figure 1 upper left frame), and improve best fit between modeled and observed velocities (Figure 1 lower left and lower right frames). The grid was used by ECCO2 to run an ocean circulation model to recover melting rates under the ice shelf.

b. Data transfer routines between ISSM and ECCO2

In order to transfer data between ISSM and ECCO2, transfer routines were developed in Matlab. The routines extract from an ISSM mesh the data relevant to a specific ECCO2 grid, and expand this data onto the rest of the grid. Routines that do the exact opposite were developed, to transfer data from ECCO2 to ISSM.

These routines are simple enough that they could be encoded into different languages, such as C/C++/Fortran, used in ISSM and ECCO2.

2. Test integrations, adjustment, and evaluation

a. Downselection to Pine Island Glacier

Pine Island Glacier (Antarctica) has been experiencing strong acceleration in the last decade, which can only be explained by a sudden perturbation near the grounding line [2]. This perturbation is probably of oceanic origin [3], but the link between ocean warming and ice sheet acceleration has not been proven. As such, this basin presents a perfect testbed for implementing and evaluating a model that couples ice flow and ocean circulation. We therefore decided to focus the project on Pine Island Glacier itself.

The regional model implemented here relies on a 1-km grid, high-resolution ocean model as well as subkilometer resolution on the ice sheet. The component model configurations and the scenario for running the coupled ice/ocean model in Pine Island Glacier is explained in the next section.

b. Ocean model component

The ocean model component of this study is integrated on a 640 by 640 horizontal grid with 1-km grid spacing and 50 vertical levels. Open boundary conditions are provided by a global ocean and sea ice solution generated by the Estimating the Circulation and Climate of the Ocean, Phase II (ECCO2) project [4]. Figure 4 shows an example result from this simulation, the Sea Surface Temperature (SST) on March 10, 1992. Of importance to realistic high-latitude ocean simulations is the correct representation of bottom boundary layers. Specifically, cold or saline dense water that sinks to the bottom needs to flow downslope in a thin (~20 m) layer. Because of limited horizontal and vertical resolution, this downslope current cannot be resolved explicitly in the above configuration. Instead, we have parameterized these currents using an embedded bottom boundary layer.

c. Transient runs using 0^{th} order melting rates

At the time of this interim report, we were able to run a first-order projection of Pine Island ice flow dynamics, using constant melting rates provided by the ECCO2 ice shelf cavity model. The run lasted 20 years, starting from 2000. The velocity results are presented in Figure 3. Thicknesses provided by this run were then fed back to the ECCO2 model. Further work is still required to use computed melting rates from ECCO2, but this short-term projection of Pine Island Glacier was a good proof of concept, on which more complex and exhaustive models can be built.

3. Short-term projection

This work was not carried out yet at the time of this interim report.

C. SIGNIFICANCE OF RESULTS

1. This is the first time an ice sheet model and an ocean circulation model are coupled. There is no example in the current literature of a coupled ice sheet/ocean circulation model. This project, once completed, should provide the first coupled model, to be used to model the sudden acceleration of outlet glaciers in Greenland and Antarctica. The link between ocean warming and glacier acceleration has never been modeled, which presents an opportunity for this project to yield some significant scientific results.

2. Our effort will support ongoing NASA ocean and ice sheet missions (Jason-1, OSTM, QuikSCAT, AMSR-E, GRACE, and ICESAT-1) and international agency missions that provide data to NASA PIs (InSAR data from ERS, ALOS PALSAR, Radarsat-1, Envisat ASAR). This work will demonstrate the practical use of data assimilation techniques in coupled ocean and ice sheet modeling, thereby illustrating the usefulness of satellite data to produce better models; it also will provide guidance for the derivation of the science requirements of future missions such as GRACE-2, DESDYN-I, SWOT, and ICESAT-2.

D. NEW TECHNOLOGY

No NTR was filed for new technology. The project resulted in new capabilities in ISSM and ECCO2 for transferring data between both models. The code is still in the validation/ verification stage, and should be completed in February 2011, at the end of this project. The project also resulted in the development of a bottom boundary layer parameterization for the ocean model used by the ECCO2 project: the Massachusetts Institute of Technology general circulation model (MITgcm). This parameterization is a critical component for realistic simulations of ocean/ice shelf interactions. The code is checked in the MITgcm CVS server so that it can be evaluated and improved by other MITgcm users.

E. FINANCIAL STATUS

The total funding for this task was $200,000, of which $159,190 has been expended.

F. ACKNOWLEDGEMENTS

We want to acknowledge the Office of the Chief Scientist and the Chief Technologist for funding this project.

G. PUBLICATIONS

None.

H. REFERENCES

[1] M. Morlighem, E. Rignot, H. Seroussi, and E. Larour, “Spatial Patterns of Basal Drag Inferred Using Control Methods from a full-Stokes and Simpler Models for Pine Island Glacier, West Antarctica,” *Geophys. Res. Lett., American Geophysical Union* **37** (2010): p. L14502.

[2] A. J. Payne, A. Vieli, A. P. Shepherd, D. Wingham, and E. Rignot, “Recent Dramatic Thinning of Large West Antarctic Ice Stream Triggered by Oceans,” *Geophys. Res. Lett., American Geophysical Union* **31** (2004) pp. 1–4.

[3] A. J. Payne, P. R. Holland, A. P. Shepherd, I. C. Rutt, A. Jenkins, and I. Joughin, “Numerical Modeling of Ocean–Ice Interactions Under Pine Island Bay’s Ice Shelf,” *J. Geophys. Res. Oceans, American Geophysical Union,* **112** (2007): pp. 1–14.

[4] D. Menemenlis, J. Campin, P. Heimbach, C. Hill, T. Lee, A. Nguyen, M. Schodlock, and H. Zhang, “ECCO2: High-Resolution Global Ocean and Sea Ice Data Synthesis,” *Mercator Ocean Quarterly Newsletter* **31** (2008): pp. 13–21.

I. FIGURES

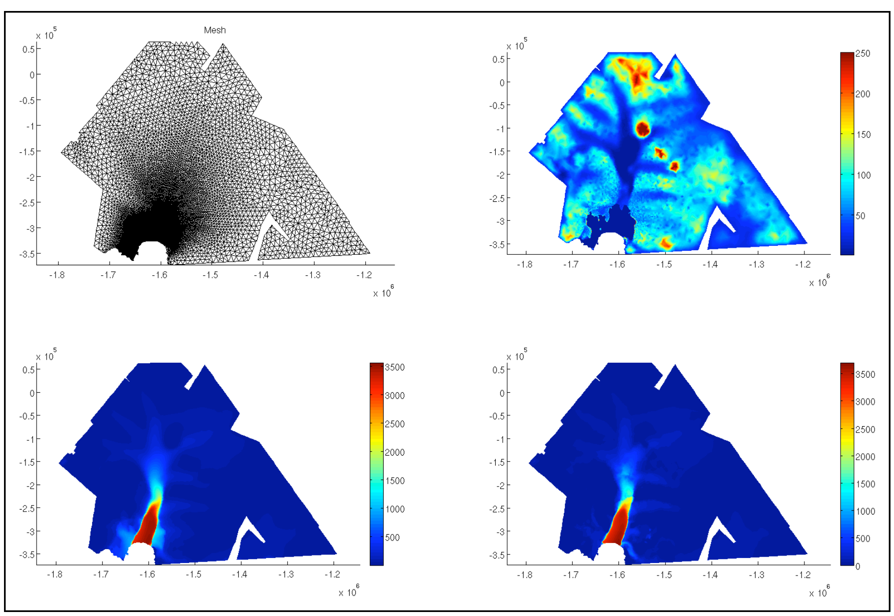

Figure 1. Model setup for Pine Island Glacier runs.

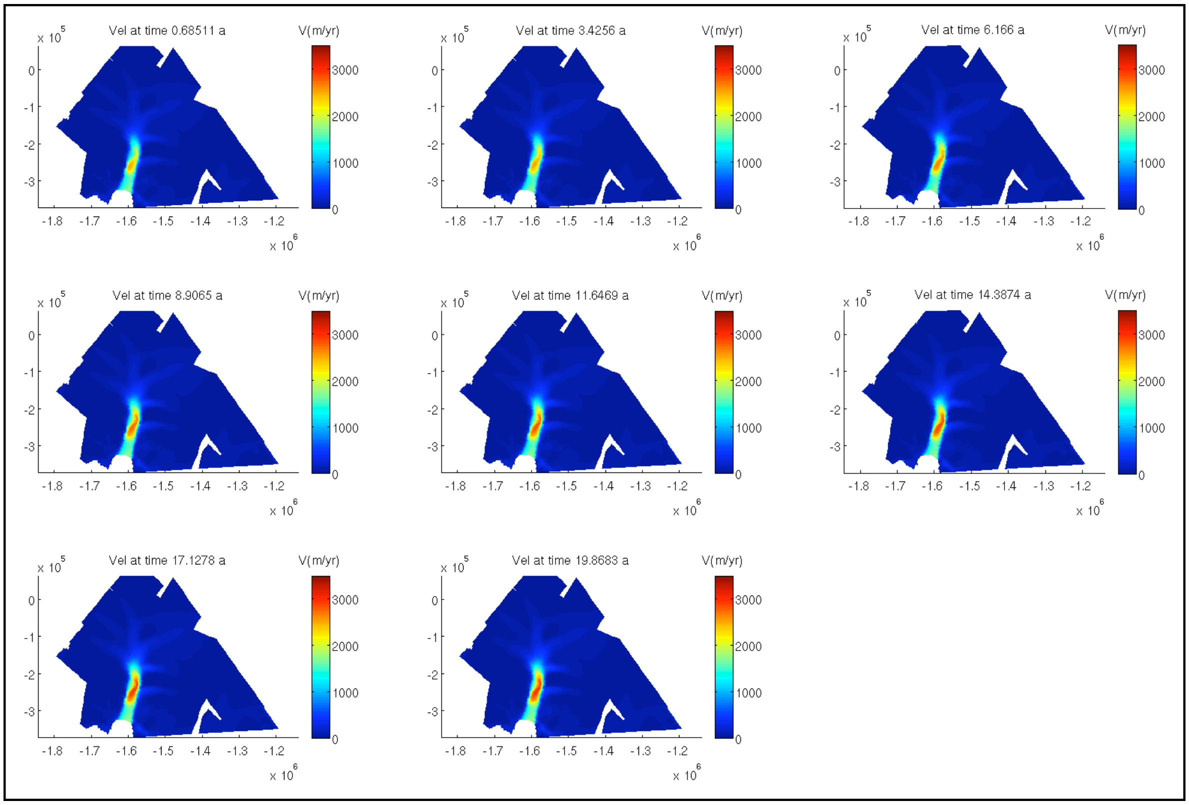

Figure 2. Data transfer between ice sheet and ocean circulation models.

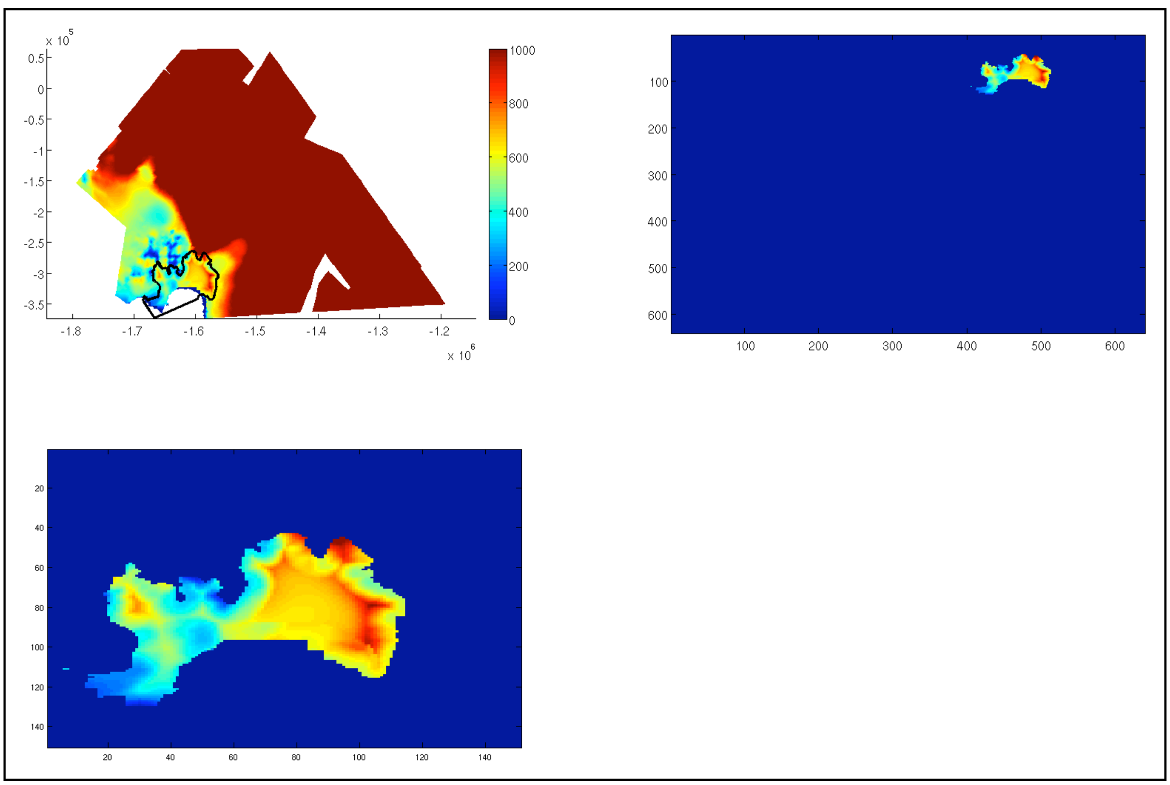

Figure 3. Transient velocities over 20 years projection, starting 1996, using constant melting rate provided by ECCO2 ice shelf cavity melting rate.

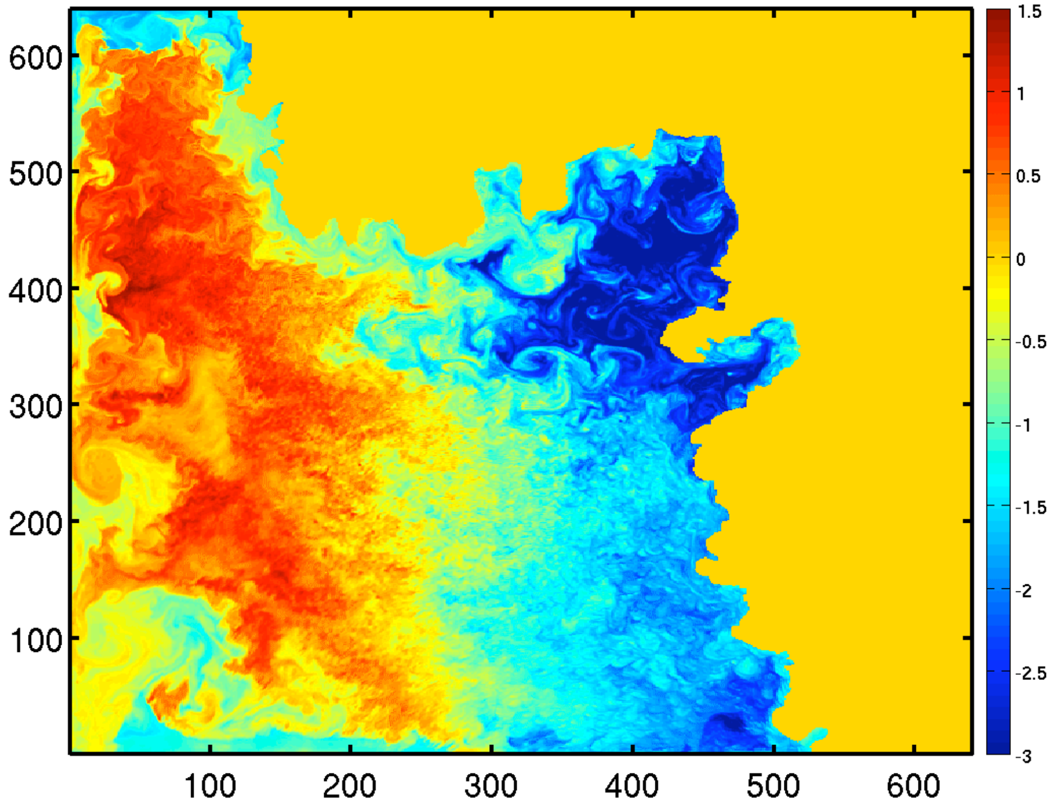

Figure 4. Sea surface temperature (10 March 1992).